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Huronian Stratigraphy and Sedimentation in the Cobalt Area

**by
Andrew Legun**

1986



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FOREWORD

This study comprises a detailed sedimentological investigation in the Cobalt area of the sedimentary rocks of the Gowganda Formation (Huronian Supergroup) and an interpretation of their depositional environment. A basement contour map based on a computer assisted analyses of diamond-drillhole data represents the Archean topography beneath its cover of Huronian sedimentary rocks. The source, timing, and processes of Ag-Co mineralization and guidelines for exploration are discussed.

The study is an integrated part of an effort undertaken to develop concepts which would relate widespread and varied mineralization in the general Sudbury-Cobalt region.

V.G. Milne

Director

Ontario Geological Survey



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Conversion Factors for Measurements in Ontario Geological Survey Publications

If the reader wishes to convert imperial units to SI (metric) units or SI units to imperial units the following multipliers should be used:

CONVERSION FROM SI TO IMPERIAL

SI Unit	Multiplied by	Gives
1 mm	0.039 37	inches
1 cm	0.393 70	inches
1 m	3 280.84	feet
1 m	0.049 709 7	chains
1 km	0.621 371	miles (statute)

CONVERSION FROM IMPERIAL TO SI

Imperial Unit	Multiplied by	Gives
1 inch	25.4	mm
1 inch	2.54	cm
1 foot	0.304 8	m
1 chain	20 116.8	m
1 mile (statute)	1.609 344	km

LENGTH

1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
1 m	3 280.84	feet	1 foot	0.304 8	m
1 m	0.049 709 7	chains	1 chain	20 116.8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km

AREA

1 cm ²	0.155 0	square inches	1 square inch	6.451 6	cm ²
1 m ²	10.763 9	square feet	1 square foot	0.092 903 04	m ²
1 km ²	0.386 10	square miles	1 square mile	2 589 988	km ²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha

VOLUME

1 cm ³	0.061 02	cubic inches	1 cubic inch	16.387 064	cm ³
1 m ³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m ³
1 m ³	1.308 0	cubic yards	1 cubic yard	0.764 555	m ³

CAPACITY

1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	4.546 090	L

MASS

1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	31.103 476 8	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	0.453 592 37	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	907.184 74	kg
1 t	1.102 311	tons (short)	1 ton (short)	0.907 184 74	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	1016.046 908 8	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	1.016 046 908 8	t

CONCENTRATION

1 g/t	0.029 166 6	ounce (troy)/ton (short)	1 ounce (troy)/ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ton (short)	1 pennyweight/ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

1 ounce (troy)/ton (short)	20.0	pennyweights/ton (short)
1 pennyweight/ton (short)	0.05	ounce (troy)/ton (short)

NOTE—Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries published by The Mining Association of Canada in cooperation with the Coal Association of Canada.

Huronian Sedimentation in the Cobalt Area

**by
Andrew Legun**

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Toronto, Ontario.

Manuscript approved for publication by John Wood, Chief Geologist, Ontario
Geological Survey, March 23, 1984. This report is published by permission of V.G.
Milne, Director, Ontario Geological Survey.

Abstract

In the Cobalt area, folded and faulted Archean metavolcanics are overlain unconformably by sediments of the Coleman Member of the Gowganda Formation (Huronian Supergroup). The unconformity has considerable relief, and is depicted in a computer-produced basement contour map based on over 1200 control point elevations of irregular distribution. Erosion along basement faults played a role in the formation of basement depressions. However, these faults were not active during the deposition of the Coleman Member.

To the east of the Cobalt area, Lorrain Formation arenites rest unconformably on Coleman Member sediments or basement, while to the west, Firstbrook Member mudstones overlie Coleman Member sediments. The deposition of the Firstbrook Member sediments to the west may correspond to erosion and reworking of Coleman Member sediments to the east. In the Cobalt area, a condensed Huronian sequence is present having unconformities and/or periods of non-deposition.

Within the region of the Cobalt Embayment, the Firstbrook Member covers at least 2500 km² and is up to 620 m thick. It clearly warrants Formation status.

Regionally, deposition of Coleman Member sediments buried the Archean volcanic basement, while granites tended to remain positive areas until they were buried by Lorrain Formation arenites and quartzites.

Deposition of Coleman Member sediments first filled the basement valleys and then onlapped the basement highs. Thus, the relief of the depositional surface decreased with time. Sedimentological evidence such as paleocurrents, provenance of clasts, basement onlaps by siltstones and sandstones, lithological associations, and the presence of a dropstone facies, indicates that the basement topography was largely drowned at the time of sedimentation and that most of the deposits are subaqueous.

Evidence for a glacial origin for the sediments is given, including the description of features previously unrecognized in the area. These are hummocky depositional surface, discrete clast-type concentrations, and pentagonal clast outlines.

Two depositional models are briefly proposed, one is based on a glaciolacustrine (or fjord) valley sediment association and the other is based on a floating ice margin similar to that bordering Antarctica. The latter model is preferred by the author as the direction of source, for exotic clasts appear to be unrelated to the alignment of valleys in the basement topography. It is suggested that most sedimentation occurred where submerged ice became grounded on the sea floor. Other processes such as mass gravity flow were probably involved in resedimentation of glacial sediments, particularly to deeper and more distal basins of the Cobalt Embayment. A single depositional model may not be appropriate as fluctuating water levels probably dramatically changed sedimentation patterns from time to time.

The petrography of the more arenaceous lithologies of the Coleman Member is described in this paper. The most striking feature is a pervasive alteration which extends into the exotic clasts.

Various theories as to the origin and source of the Ag-Co veins mined in the region are evaluated. It is concluded that:

1. Ag-Co veins may be of more than one age. Crosscutting relationships between veins then indicate only the latest period of mineralization.
2. The ore minerals at Cobalt probably came from the same reservoir as that of the Nipissing Diabase. The alternative is to have diabase as a heat source acting on fluids within the sediments. This, however, leaves unexplained why or how elements such as Ag were reconcentrated to a great degree from trace amounts in host rocks, but the considerably more abundant elements of base-metal sulphides were not.

A basement contour map based on computer assisted analyses of diamond-drill data represents the Archean topography that is overlain by the Huronian metasediments. It was used to interpret the depositional environment of the Gowganda Formation sedimentary rocks.

Huronian Sedimentation in the Cobalt Area; Ontario Geological Survey Miscellaneous Paper 124, 24p. Accompanied by 3 Charts. Published 1986. ISBN 0-7729-0589-4.

Introduction

Field work carried out during the summer of 1981 comprised detailed stratigraphic and sedimentological studies of the Huronian sediments in the Cobalt area. These studies were an ongoing phase of a program (see Wood 1979, 1980) to study the regional stratigraphy and sedimentology of the Cobalt Embayment.

In the Cobalt area, folded and faulted Archean metavolcanics, and metasediments are overlain unconformably by sediments of the Coleman Member of the Gowganda Formation (Huronian Supergroup). The unconformity has considerable relief. To the east of the study area, the basement-sediment configuration is hidden under the cover of an undulating sill-like body of Nipissing Diabase. Related to the Nipissing Diabase is Ag-Co vein mineralization for which the area is historically famous.

Project activities were directed toward the following goals:

1. producing a surface geology map of the Cobalt area that emphasized the stratigraphy of the Coleman Member Sediments at a scale of 1 inch to 400 feet.
2. producing a computer map of the basement topography based on surface and subsurface data (scale 1 inch to 400 feet)
3. determining the relationship between basement topography and stratigraphy
4. determining the environment of deposition of Coleman Member sediments and the role of the basement as a source of sediment
5. relating, if possible, basement topography to the pattern of distribution of Ag-Co ore veins.

The surface geology map is bounded by Latitudes 47°22'N to 47°24'30"N and Longitudes

79°40'W to 79°42'W. It includes the town of Cobalt and the surrounding district, an area about 13 km² in size. The area is readily accessible by Highway 11B through Cobalt and by numerous township roads. Specific localities outside the map area were also examined and these are referenced in the text. Sub-surface examinations were made at the Silverfields Mine.

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Dave Thompson - Winter assistant, Ontario Geological Survey

Brian Thorniley - Geologist, Agnico Eagle Mines Limited

Regional Geologic Setting

The Huronian sedimentary rocks in the Cobalt area are represented by the Gowganda and Lorrain Formations of the Cobalt Group (Table 1). Thomson (1957) was able to map in the Cobalt region two distinct units within the Gowganda Formation which he referred to as the Coleman Formation and the Firstbrook Formation. The words Coleman and Firstbrook have gained acceptance only as Members, not as Formations. However, a compilation by D.S. Thompson included in his report (see Appendix) suggests that the Firstbrook is a definable unit within an area of >1000 square miles. The author considers that the absence of an equivalent mappable reddish mudstone in the Sudbury region is not an argument against its recognition as a mappable unit in the Cobalt region.

The Firstbrook Member is not present within the author's map area. It is exposed 2.5 km to the west and reaches considerable thickness (>200 m, Thomson 1960). To the east of the map area, the Coleman Member is directly overlain by arenites of the Lorrain Formation.

Within the immediate Cobalt region, either Coleman Member, Firstbrook Member, or Lorrain Formation may rest on Archean basement. The Coleman Member (and Firstbrook?) may rest on either Archean granitic or volcanic rocks. The Lorrain Formation rests on granitic terrain and rarely if ever on Archean volcanic rocks. Apparently, some basement highs were positive areas during Coleman deposition and were finally buried by Firstbrook Member sediments (for example, Archean outlier in Firstbrook Township, Johns 1980). Other basement highs remained positive areas until Lorrain Formation arenites buried them. These basement highs were also a source of sediment. Volcanic and granitic basement contributed to Coleman Member deposits, while granites were the

principal contributors to Lorrain Formation arenites. Thus, the granites persisted as positive areas at a time when Archean volcanic terrain was largely buried by Coleman Member sediments.

Twenty km east of the Cobalt area, Henderson (1936) observed that exposures of Lorrain Formation quartzites were topographically lower than Coleman Member sediments, and concluded that Coleman Member sediments underwent erosion before the deposition of Lorrain Formation quartzites. East of Cross Lake (Figure 1), Coleman Member sediments were reworked before Lorrain arenites were deposited. This period of erosion to the east and non-deposition at Cobalt may correspond to the deposition of Firstbrook Member laminated mudstones to the west.

Relative to Cobalt, the main depocentre of Huronian sedimentation was to the west and northwest. At Cobalt and to the east, a relatively elevated terrain was present. As a result, a suite of lithologies somewhat thinner and atypical of the Cobalt Embayment is present in the mapped area. The Huronian stratigraphic sequence is condensed with unconformities and the Coleman Member sediments are clast rich. This contrasts with the great thickness (2032 feet of Firstbrook Member rock overlying >2361 feet of Coleman Member rock; the reader should consult the metric conversion chart shown opposite page 1 to convert to SI units) in Henwood Township (Thomson 1968) where a "distal" clast-poor facies of the Coleman Member is present.

The deep basins of the Cobalt Embayment may correspond to areas underlain by Firstbrook Member. The assumption is that Firstbrook Member sediments were deposited in topographic basins that were incompletely filled by Coleman Member sediments.

TABLE 1. TABLE OF PRECAMBRIAN LITHOLOGIC UNITS FOR THE COBALT AREA.

PRECAMBRIAN

MIDDLE PRECAMBRIAN

MAFIC INTRUSIVE ROCKS

NIPISSING DIABASE

Intrusive Contact

HURONIAN SUPERGROUP

COBALT GROUP

Lorrain Formation
Arenites.

Gowganda Formation

Firstbrook Member
Reddish Mudstones.

Coleman Member
Breccia, siltstone, wacke, conglomerate, grit,
and arenite.

Unconformity

EARLY PRECAMBRIAN

METAVOLCANICS AND METASEDIMENTS

Mafic and felsic metavolcanics and associated metasediments.

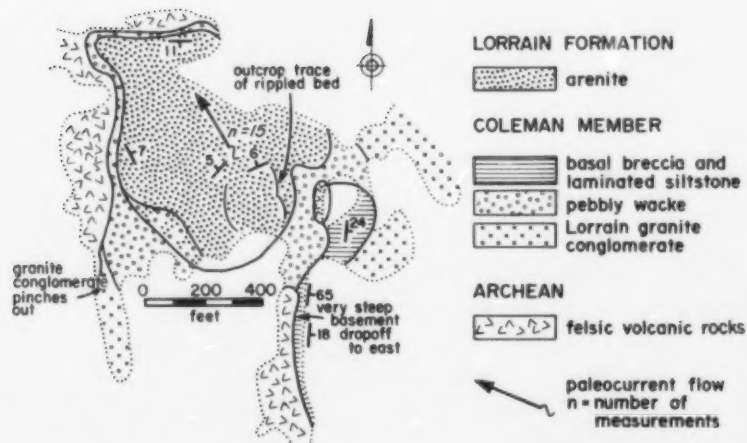


Figure 1. Geology in the vicinity of the Lorrain Formation outcrop east of Cross Lake.

Cobalt Area — Basement Rocks

The considerable relative relief (>600 feet) is depicted in the basement contour map. Generally, the relief consists of north-northeast trending basement ridges with intervening troughs. The principal troughs underlie Cart Lake and Cobalt Lake. The latter is truncated by the uplifted margin of the Cobalt Lake Reverse Fault. More minor depressions include:

1. the north-trending Silverfields paleovalley that cuts northwest across a basement ridge and connects with the Cart Lake trough
2. a southeast-trending valley on the side of the Cobalt Lake trough
3. a valley descending to the north from the Kerr Lake Arch
4. a northeast-southwest linear feature associated with the Cyril Lake Fault
5. shallow northeast-trending basin at the Nipissing 407 Mine.

According to Patterson (1979), the predominant volcanic rock type in the Cobalt area consists of pillowed mafic volcanic rocks with discontinuous layers of hyaloclastite marking flow tops. Sill- and dike-like bodies are also present. Interflow sediments include breccias, tuffs, cherts, wackes, "iron formation", and carbonaceous rocks. Felsic volcanic rocks are present east of Cross Lake, at Kerr Lake; in the subsurface, and near the Montreal River which is 14 km south-southwest of the map area. Felsic volcanic rocks range from dacitic to rhyolitic in composition and include feldspar-quartz porphyries and siliceous tuffs.

Cobalt Area — Basement Topography and Sedimentation

INTRODUCTION

Erosion has preferentially occurred along basement faults giving rise to the northeast-trending paleovalleys. In the map area faults aligned with some of these valleys, for example, the Cobalt Lake Fault and the Valley Fault displace sediments, and indicate that the valleys are structural zones of weakness. Valleys were probably eroded along pre-Huronian faults that were reactivated after sedimentation of the Huronian strata. There is no indication that faults in the Cobalt area were active during sedimentation.

At New Lake which is 12 km south-southeast of the map area, a sinuous exposure of Coleman Member sediments apparently buries an ancient fault valley. At the southeastern corner of New Lake, the exposed basement still topographically confines these sediments! The Columbus Fault southeast of Giroux Lake occupies a valley cut into the present bedrock surface. At the Cleopatra Mine, this same fault occupies a valley buried by Huronian sediments.

BEDDING, AND BASEMENT TOPOGRAPHY

Bedding in Coleman Member sediments tends to follow the basement slope, but at lower values of dip. It is obvious in many cases that the dip of the bedding is not primary, but a result of compaction against basement highs. This is most evident east of Cross Lake (Figure 1) where laminated siltstones rest undisturbed on a 60° basement slope. Within the map

area, laminated siltstones drape away from the exposed basement high of "Nipissing Hill" with dips decreasing away from the "Hill".

The bedding dip is low (usually <5 cm) and varied. The dip of the present land surface commonly follows the bedding. Vertical stratigraphy is observed in ridges and vein cuts.

The stratigraphic succession overlying basement varies from place to place (see Chart A, back pocket). Some units persist while others dramatically thicken or thin. For example, at Little Silver vein located southwest of Nipissing Hill, a sandstone unit overlies 59 m of sediment which consists of 10.5 m of laminated siltstone and 48.5 m of pebbly wacke. The sandstone unit may be traced along a ridge to the southwest where it is within a few m of basement. Similar onlap on basement occurs northeast of Nipissing Hill (see sandstone unit in Figure 2) and in the Silverfields paleovalley. Knight (1924), and Thomson (1961) documented pinching of units against basement. A laminated siltstone that pinched against one side of a basement knob was found at the same elevation on the other side (Thomson 1961, p.92). Pinching and onlap of units against basement highs indicates that sediment filled the basement lows and subsequently overlapped the basement highs. Thus, the relief of the depositional surface decreased as greater areas of the basement topography were buried under an increasing thickness of sediment.

Lithologies of the Coleman Member

Rocks of the Coleman Member were lithologically subdivided as follows with percentage clasts of pebble size or larger indicated by the numbers in parentheses: conglomerate (>30), pebbly wacke (5 to 30), sparsely pebbly wacke (<5), sandstones, grits, siltstones, and breccias [no figure given].

The lithologic spectrum is dominated by wackes of greatly varied clast type and concentration. These can be transitional into the other lithologies which show some evidence of sorting and fabric. Sparsely pebbly to pebbly wackes are typically unbedded. Clasts are usually randomly distributed, but can be concentrated along layers or in irregular zones (Photo 1). The matrix is unsorted, but is observed to vary in grain size from silt to grit.

The sparse pebbly wackes merge, or are interbedded with laminated siltstones having "dropstones". The contact can be sharp or transitional. A transitional lithology is represented by non-laminated siltstone having sparse clasts.

Siltstones can be massive, laminated, including couplet bedding (Photo 2), or rippled. These rocks can be found interbedded with any other lithology.

Sandstones, grits (2 to 4 mm grain mode), and small pebble conglomerates can be massive, graded, or crossbedded.

Basal breccias consist of angular fragments of the immediate bedrock upon which these rocks rest or into which they merge. These breccias can be draped by laminite or grade upward into other lithologies such as pebbly wacke.

A basal breccia is shown in Photo 3. It grades from fractured basement to slightly separated angular blocks, to rotated and dislocated blocks within a clastic matrix. In many areas, a basal breccia is not present. It can occur on basement highs as well as lows (for example, the Silverfields paleovalley. East of Cross Lake (Figure 1) it is present at the steep edge of a basement slope, but elsewhere, northwest of Nipissing Hill, slopes are not steep. The best exposures of basal breccia in the area are at the latter location (Photo 3).

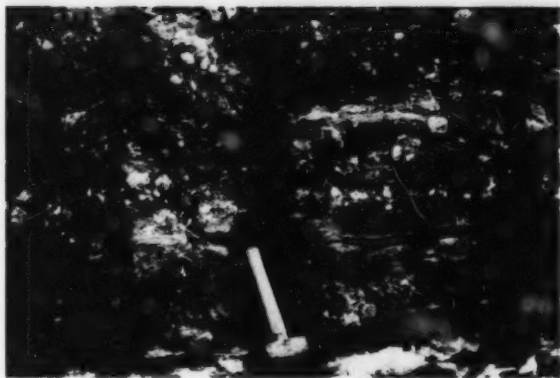


Photo 1. The exposure of pebbly wacke shows irregular pebbly zones toward the top and a laminated zone toward the base. It may represent deposits of waterlain till. Location: By Cobalt Lake opposite section JK on Chart A.

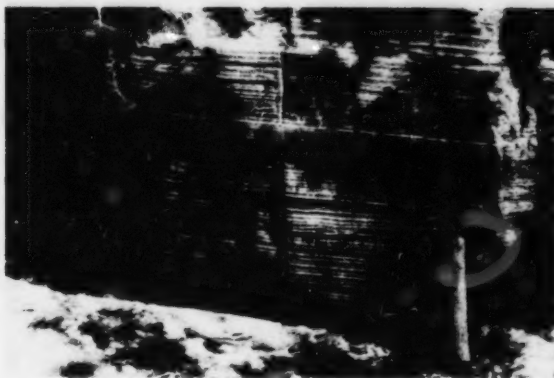


Photo 2. The laminated siltstone shows distinct alternations of finer (light) and coarser (dark) sets of laminae. Location: Section AB on Chart A at southern border of Nipissing Hill.



Photo 3. An exposure of basal breccia merges into basement at the bottom of the photo and into Coleman Member sediments at the top of the photo. Location: Southwestern edge of basement knob to north of Nipissing Hill (see Figure 2).

Lithologic Associations

Stratigraphic mapping in the area depends on tracing accurately the siltstones, sandstones, and conglomerates. These lithologies may be traced up to about 1 km. The contact between siltstone and overlying conglomerate is easily traced. It can be sharp and surprisingly uniform, or erosional with rip-up clasts of the underlying siltstone evident. The lower contact of pebbly wackes can also be an erosional boundary (see cross section EF on Chart A, back pocket).

The association of lithologies in some areas is not coherent. Such areas include the southern border of Nipissing Hill, the Coniagis pit, and the top of the ridge at the Little Silver vein. Features may include patches of laminated siltstone on a smooth outcrop surface, varied bedding attitudes, recumbent (slump?) folds, lumps of one lithology in another, and sudden changes in clast density and matrix. Some of these features can be attributed to the manner in which the outcrop surface cuts across a depositional surface. For example, patches of laminated siltstone may represent the drape over the hummocky top surface of a pebbly wacke. The "hummocks" are cut by the plane of exposure, this results in the siltstone filled depressions being left as patches. An intact hummocky surface is shown in Photo 4. Where the plane of exposure shallowly cuts across two contrasting beds, the lower bed a conglomerate and the upper bed a siltstone, an erroneous impression can be given to the viewer of conglomerate changing laterally into pebbly wacke and then into siltstone.

At the Little Silver vein, the north-south cliff section is stratigraphically well ordered: laminated siltstone is followed by sandstone and conglomerate. At the top of the ridge, the conglomerate rapidly pinches out toward the north. Laminated siltstone depressions occur and sandstone "lumps" float in wacke. A slump fold is discernible at the cliff edge. Toward the east over the ridge top and down to the road there is a confusing association of grit, laminated siltstone, and boulder conglomerate. At the road, the laminated siltstone found at the base of the Little Silver vein can be discerned, but the overlying units have vanished.



Photo 4. The top surface of the pebbly wacke is hummocky and draped by laminated siltstone. Location: Immediately west of Valley Fault (and south of fault 64).

Irregularities in bedding include vertical contacts between lithologies. Thomson (unpublished manuscript) mentioned a vertical contact between conglomerate and arenite on Highway 11 near Latchford. Within the map area, in the Silverfields Mine, a conglomerate is in vertical contact with siltstone. Projections of conglomerate (a few dm thick) extend from the contact into the siltstone. Bedding surrounding the projections is undisturbed. The conglomerate that is in vertical contact with the siltstone may be in the same way as that described by Halls and Stumpf (1970) and used in their cross section as the nose of conglomerate projecting into the valley from the side.

On the western side of Nipissing Hill, the author has observed a small wedge-like body of conglomerate 1 m or so wide merging on all sides into undisturbed siltstones.

In the Cobalt area, there are 3 major reasonably coherent lithologic associations:

1. a dominant association of siltstone and pebbly wackes - interbedded and/or laterally merging
2. a poorly defined upward fining association of conglomerate - grit + sandstone + siltstone
3. A well-defined upward coarsening association of siltstone - sandstone - grit conglomerate

Lithologic associations 2 and 3 are usually overlain by lithologic associations 1. Associations 2, and 3 are described in the sections which follow this one.

UPWARD FINING ASSOCIATION

In the northern half of the map area and west of the Cobalt Lake Fault vertical stratigraphy shows that three conglomerate grit-sandstone sequences are present separated by pebbly wackes. The second sequence is repeated by the Valley Fault. The third pinches out to the south.

The conglomerates have a wacke matrix and vary from clast-supported to matrix-supported. Clast-supported conglomerates tend to be at the base with granitic boulders evident. Upwards, the amount of matrix increases and clast size tends to diminish; however, the occasional boulder is still found. No fabric is observed. Small pebble conglomerates become interbedded with grits and eventually grade into sandstones. Sorting is present in the "grit" part of the sequence, and graded beds are occasionally observed. These crudely fining upward sequences are up to several 10s of m thick and subsurface data suggests they thicken and thin in an irregular manner. These sequences are not present to the south where pebbly wackes and siltstones dominate, except for a distinct basal sequence at the entrance to the Coniagis pit. This basal sequence consists of normally graded beds of conglomerates with coarse tail grading, and stratified sandstones (Photo 5). Sandstones interbedded with laminated siltstone and very thin beds of grit follow. Dropstones are present. Laminated siltstone beds thicken, the sandstones thin, and the sequence fines upward into massive siltstone and mudstone. This in turn is overlain by much thicker (<15 sparsely pebbly wacke and laminated siltstones. These units in places grade laterally into each other. The stratigraphy is somewhat obscurely visible on the fresh blasted walls of the

Coniagis pit. The stratigraphy bears little resemblance to the stratigraphy to the north where 3 conglomerate-grit sequences were identified.

UPWARD COARSENING ASSOCIATION

Southwest of Cobalt, in the vicinity of Short and Brief Lakes, an upward coarsening sandstone-grit-conglomerate sequence is traceable along several ridges. A northwest-southeast trending ridge (section CD on Chart A, back pocket) shows that the sequence visibly thins away from the basement and probably pinches out in siltstones. In Red Jacket Shaft, the upward coarsening sequence is 25 m thick and from top to bottom is described as: conglomerate (9 m); quartzite, arkose, grit, and grit conglomerate (11 m); and well-bedded greywacke (4.5 m) resting on 4.5 m of basal conglomerate (Thomson 1960, p.29).

Two other upward coarsening sequences are well exposed immediately to the northeast and southwest of Nipissing Hill. The latter is the well known Little Silver vein section previously mentioned. Both sequences show laminated siltstones at the base interbedding upward with sandstones exhibiting load casts, ripple drape, and ripple drift (Photo 6). These grade upward into planar crossbedded sandstones and grits which are overlain sharply by clast- and

matrix-supported conglomerates. The sandstones of both sequences appear to pinch out normal to the strike of the beds. In the former sequence, this is observed in a southwesterly trending vein cut. In the latter sequence, it is inferred from limited surface and subsurface sections.

NOTES ON CROSS SECTIONS FROM GEOLOGIC MAP

Seven small cross sections are shown on the geological map (Chart A, back pocket) and are described as follows:

AB - A conglomerate unit (2f), which includes boulders over 1 m diameter in size, is observed to thin to 1 m and then thicken to 2 m near the road. The conglomerate is overlain by laminated siltstone that displays striking light and dark couplets (varves?). Near the road, a very undulating bedding surface is present originating from the drape of laminated siltstone over boulders of the underlying conglomerate.

CD - An upward coarsening sequence similar to that already described. Even though the sequence thickens towards exposed basement, it is not derived by erosion of basement material because many of the clasts are exotic.

EF - This section exhibits an unconformity. Deposition of pebbly wackes included assimilation of underlying lithologies.

G - This section shows an arcuate exposure of conglomerate on a sloping outcrop. A vertical face at the lower end of the slope shows a downcutting truncation of sandstones by the conglomerate. Separate concentrations of granitic and volcanic clasts are present within the conglomerate suggesting release of material from grounded ice.

HI - An upward coarsening sequence is present within a small basement embayment. The embayment



Photo 5. A graded conglomerate bed overlain by stratified sandstone. This exposure is in the Coniagis pit.

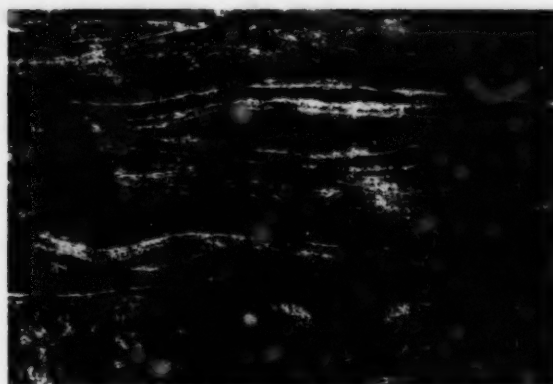


Photo 6. Above the finger, ripple drift (type A cross lamination) is preserved and overlain by draped lamination. This represents a decrease in bed load transport relative to suspended load. These bedforms are part of an upward coarsening sequence exposed to the northeast of Nipissing Hill. (see Figure 2).

is bounded on the east by an exposed basement knob. South of the knob, siltstones overlie a basal pebbly wacke while in the embayment (depression) these siltstones overlie the upward-coarsening sequence. This small section is an example of rapid lithological changes over 10s of m related to basement topography.

JK - A unit of laminated siltstone pinches out against a basement high. Where it thins, pebbly wacke rests on basement as well as overlying the laminite. The edge of the laminite may represent deposition at the edge of a body of water where the

water overlapped the rocky shoreline of "Nipissing Hill". Weakly asymmetric ripples in siltstone that rest on the basal pebbly wacke are directed "onshore". The siltstone, before pinching out, becomes sandy and shows evidence of reworked sediment (siltstone clasts, and so on). The same laminated siltstone forms the lower part of the upward coarsening sequence northeast of Nipissing Hill.

L - A conglomerate (wacke matrix) overlies with an erosional contact, a finely laminated siltstone. The conglomerate grades upward over a few m into pebbly wacke.

Provenance

Exotic clasts are invariably present in all clast-bearing lithologies, although they are scarce in basement derived breccias. Clasts in Coleman Member sediments can be grouped into 4 categories with regard to their source. These include clasts of:

1. the local bedrock (includes lamprophyre, diorite, iron formation, pillowed basalt, and interflow sediments)
2. Lorrain granite that is exposed to the southeast
3. dacitic quartz feldspar porphyry known to occur east of Cross Lake in surface and subsurface exposures
4. granitic, granodioritic, conglomeratic (minor), gneissic (minor), syenitic rocks. The conglomerate may be Timiskaming (exposed to north). The closest gneiss locality known is in Quebec (Henderson 1936).

A particularly good exposure of a diverse assortment of clast types can be seen off the shoulder of Ragged Chutes Road 1 km south-southwest of Peter-son Lake.

Clasts of Lorrain granite are distributed within the sediments over a wide area to the north and west of present exposures of the granite. For example, the odd clast is found on the southern shore of Short Lake, in ridges east and north of the Valley Fault, and in a ridge north of Cobalt on Highway 11. In subsurface, "conglomerate" with reddish granite clasts, possibly Lorrain, is described as occurring near the bottom of the Cart Lake trough (Thomson 1961, p.64). Lorrain granite is generally recognizable owing to the redness of its feldspars and the distinct blob-like interstitial quartz which is occasionally present in graphic outline.

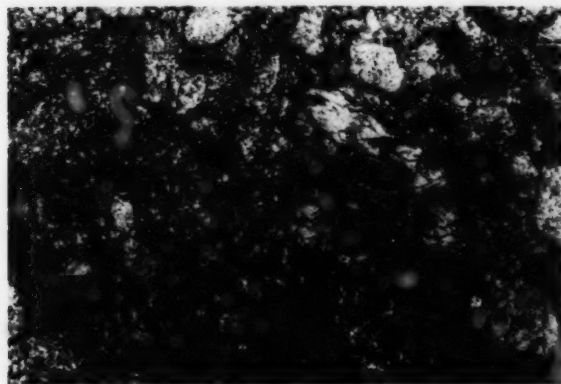


Photo 7. A conglomerate consisting predominantly of pebbles and cobbles of Lorrain granite is shown. The other fragments (for example below lenscap) are volcanic. Note the gritty matrix. This exposure is at New Lake.

Within 1 km or so of present exposures of Lorrain granite, boulder conglomerates containing clasts predominantly of this red granite are present. East of Cross Lake (Figure 1), such a conglomerate at least 15 m thick pinches out northward over approximately 200 m. The granite boulders are in striking contrast to the volcanic basement 1 m or so below. At New Lake, a similar rounded cobble to boulder conglomerate (Photo 7) is adjacent to volcanic basal breccias (see Photo 3) that are devoid of granitic clasts.

As far as the author is aware, Lorrain granite clasts are not found in sediments of the Kerr Lake area. Otherwise, the dispersion of Lorrain granite clasts from areas of exposed Lorrain granite covers a very wide area to the north and west. The other clast types, which are composed of quartz-feldspar porphyries, gneisses, suggest transport to the west.

Petrographic Notes

The petrographic study was concentrated on arenaceous sediments of the Coleman Member as these are within a suitable grain size and texturally are more revealing than the lithologically more dominant pebbly wackes.

Thin-sectioned arenites range from lithic arkose to feldspathic litharenite in composition. These rocks are composed of grains of quartz, feldspar, and fragments of granitic and volcanic rocks. Volcanic rock fragments display a variety of textures including pilotaxitic and porphyritic varieties. The chlorite content of these fragments varies suggesting they range in composition from mafic to felsic. Estimated modes of volcanic fragments range from possibly <5 to >40%. Many grains tend to be interstitial, and in some thin sections, it is difficult to estimate their abundance as they merge into a chloritized microcrystalline groundmass. In other thin sections, a varied grain sized quartz-feldspar mosaic is present. On the whole, little matrix is present in the arenites and the subangular to subrounded grains, many non-equant, are tightly packed and corroded with chloritic rims or grain to grain sutured boundaries. The proportion of quartz to feldspar varies, but on the whole is roughly equal. Albite twinning in the plagioclase is common.

Pervasive alteration is evident in the arenites. Products of alteration include interstitial networks of

chlorite and calcite or chlorite-calcite patches ("spotting"). The patches of chlorite or calcite enclose and isolate the detrital grains. Chlorite is also present as coarser fan-like aggregates or trains, and in some thin sections occurs with muscovite. Associated with chlorite and calcite spotting is bleaching and granular turbid sphene. Recrystallization, that is of quartz and feldspar into clear quartz-feldspar mosaics for example, at the third level Silverfields Mine, may be related to such alteration.

Exotic clasts in Coleman Member sediments are also altered. For example, in granitic rocks, calcite is observed to rim feldspars, and chlorite pseudomorphs after biotite are common. Even chlorite-calcite "patches" with sphene occur in the clasts. In hand specimen, these granitic clasts are observed to be impregnated with the same sulphides, for example, sphalerite and chalcopyrite, that are associated with basement volcanic rocks.

In altered conglomerates that project into siltstones on the fourth level of the Silverfields Mine, chlorite-carbonate spots, often in chains, are present in the matrix, the clasts, or overlapping both. Silicification of the volcanic clasts is extensive with replacement of feldspar microlites by quartz in trachytic-textured clasts.

Depositional Environment

ORIGIN OF BASAL BRECCIAS

Basal breccias may originate as a result of freeze-thaw action at the base of grounded ice. Alternatively, it has been proposed (Patterson 1979) that the basal breccia is a weathering product of a cold climate and was formed when the topography was subaerially exposed. However, as was mentioned previously, the odd exotic clast is found in basal breccias. This implies a relationship between a process responsible for breakage and dislocation of bedrock *in situ*, and a process responsible for transport of the exotic clasts. This process would be more compatible with the first alternative, that is a freeze-thaw action at the base of the grounded ice. Basal breccia as regolith leaves the presence of exotic clasts unexplained unless they were introduced subsequently (for example ice rafting?).

At New Lake south of the map area, a basal breccia contains fragmental aggregates redeposited with their original matrix. Pieces have matching borders and are separated by matrix which contrasts to that outside the aggregate (Photo 8). Apparently, fragments and matrix were deposited as a cohesive mass (debris flow?).

THE PRESENCE OF ICE IN THE DEPOSITIONAL ENVIRONMENT

Broken granitic boulders are well displayed in the outcrop bordering Ragged Chutes Road. In this case, the fragmental aggregates are not of local bedrock origin and were deposited some 10s of m above basement. The matrix filling the fractures of the boulders contrasts with that surrounding the boulders. How were these broken boulders transported considerable distances, at least several km, without their parts separating en route? Either considerable matrix strength kept them intact, or the broken boulders were transported while enclosed in ice.

Much of the angular material scattered throughout pebbly wackes and other lithologies above basal breccias may have been transported as debris enclosed in ice.

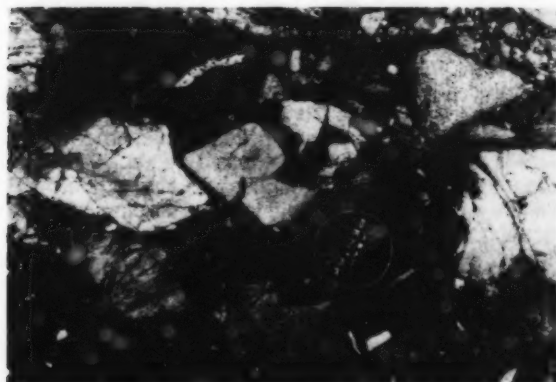


Photo 8. The basal breccia at New lake shows an angular clast aggregate (centre) that was redeposited with its matrix.

Other evidence that infers the presence of ice includes:

1. abundant dropstones resulting from ice rafting
2. the pentagonal outline of many clasts. This is typical of glacial gravels (Wentworth 1936)
3. Concentrations of exotic clast types within the pebbly wackes suggest long distance transport without mixing. Such concentrations may indicate release from grounded ice.

Basal breccias commonly grade upward into pebbly wackes with abundant exotic clasts. These pebbly wackes that may also directly rest on basement, are commonly considered to be tills. Tills, however, were not deposited everywhere because laminated siltstones, which clearly are not a till, may rest on basement.

GLACIAL DEPOSITS AND BASEMENT TOPOGRAPHY

The orientation of basement valleys as revealed by surface geology in the basement contour map appears unrelated to the source direction of many of the exotic clasts presumably transported by ice. An exception may be the long and sinuous (valley fill?) outlier of Coleman Member sediments that extends westward off the Lorrain granite at New Lake, and contains conglomerates derived from that granite.

Paleocurrents also do not reflect clast source terrain (see paleocurrents on Chart A). Paleocurrent data from crossbedding and weakly asymmetric ripples in Coleman Member sediments suggest a weakly defined northeast-southwest flow, roughly parallel to the trend of the main basement valleys. In spite of the gradients of the basement topography, sedimentary structures such as trough crossbedding which are indicative of strong unidirectional currents, are not common. Common sedimentary structures are straight crested symmetric ripples. These features, together with the following statements, indicate that the topography was largely drowned and that subaqueous processes of deposition prevailed:

1. the presence of dropstones in laminated siltstones
2. the interbedding of laminated siltstones with all other lithologies, including conglomerates
3. the presence of laminated siltstones with dropstones draping basal breccias in the Silverfields paleovalley. There is no evidence that this valley was filled by fluvial sediments
4. a lack of facies change in the laminated siltstones where they onlap basement, a possible exception is presented in section JK of Chart A, back pocket)
5. the suggested (Thomson 1961, p.92) lateral persistence of some of the siltstone ("bedded greywacke") units that mantle pebbly wackes over large areas irrespective of underlying basement topography.

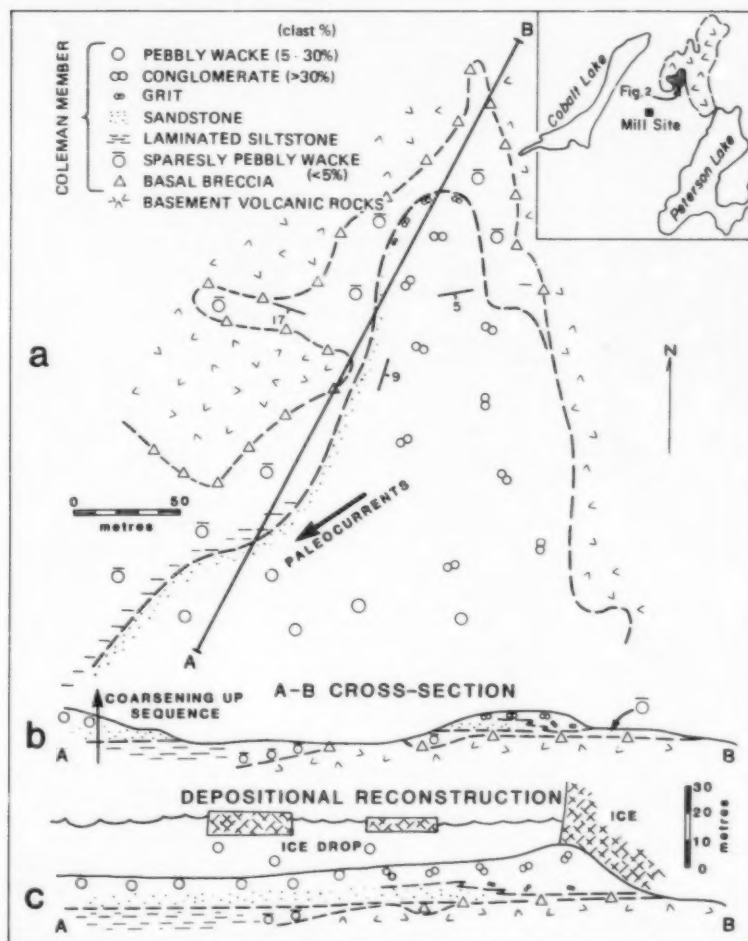


Figure 2. a) surface geology b) geological cross section c) depositional reconstruction of rocks exposed N.E. of Nipissing low grade mill site, Cobalt, Ontario.

UPWARD COARSENING AND UPWARD FINING SEQUENCES

The upward coarsening sequences could represent deposits of prograding glacial deltas that bordered basement highs. Their sediments, however, were not derived directly by erosion of these highs because they are rich in exotic clasts. Paleocurrents and lateral changes in grain size clearly indicate a northeastern source for the sequence northeast of Nipissing Hill. Paleocurrents are rather ambiguous for the other sequences, those at the Little Silver vein, Brief Lake, but thickening toward basement highs would indicate a source up the basement slope.

A prograding glacial delta sequence should be overlain by fluvial conglomerates of a subaerial outwash fan. The conglomerates and pebbly wackes overlying the delta sequence at Cobalt, however, are neither imbricate, sorted, nor channelled as might be expected if they were of a typical fluvial origin. They are till-like in nature with laminite drapes on bedding surfaces, dropstone features, and an incoherent lithological association (due to ice contact?).

The author suggests that the upward coarsening sequences may have been deposited subaqueously

under glacial ice that had grounded on the basement highs. Water, into which the outwash fans prograded, lay between the ice and basement lows. The sequence northeast of Nipissing Hill may in fact represent deposits of an esker delta (Figure 2).

Fining upward conglomerate-grit sequences may also be subaqueous. The graded conglomerate-stratified grit (see Photo 4) and sandstone sequence at the entrance to the Coniagis pit is analogous to the graded-stratified sequence of resedimented conglomerates found on submarine fans (Walker 1979). The other fining upward sequences are similar, but more till-like at the base exhibiting less grading or stratification. The "till" rests with sharp contact on lithologies probably deposited subaqueously such as laminated siltstones with dropstones, and sparsely pebbly wackes. These sequences may represent subaqueous fans at a submerged ice margin or at a grounding line of such submerged ice. Processes of both glacial deposition and mass gravity resedimentation are postulated to have occurred.

Pebbly wackes merging into laminated beds vertically or laterally probably represent a combination of normal sedimentation of laminated silt, and sedimentation of ice-rafted debris.

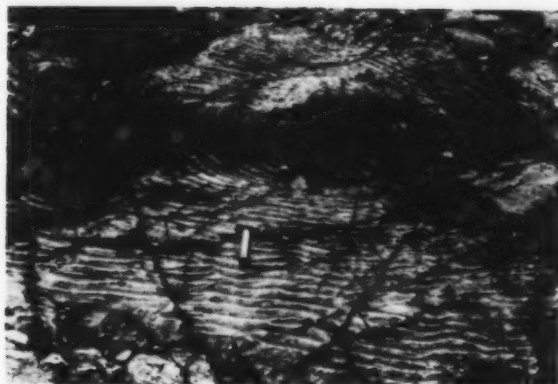


Photo 9. The rippled surface of a siltstone bed is shown. The ripples are straight crested and weakly asymmetric with the hammer head showing the direction of flow. Undulations of the bedding surface is due to hidden boulders over which compaction has occurred. Location: Northwestern corner of "Nipissing Hill" section JK on Chart A.

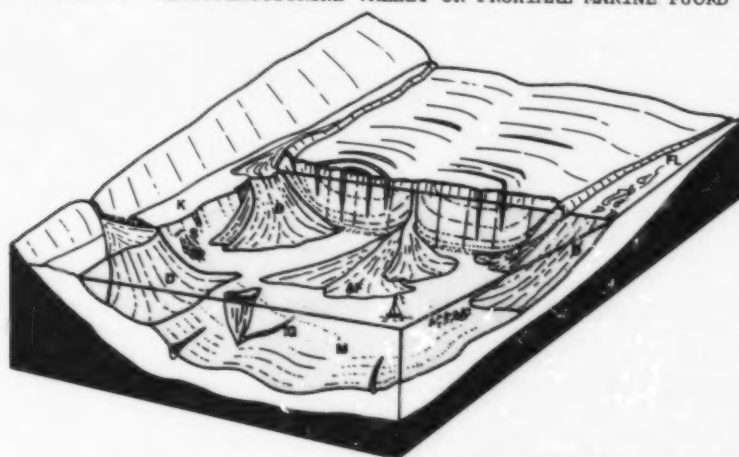
Some laminated siltstones (bedded greywackes) appear to have blanketed the pebbly wackes over large areas. Indications are that normal sedimentation, in the absence of ice, corresponded to deep water suspension deposits and density flows. This may have occurred during periods of glacial retreat.

DEPOSITIONAL MODELS

Two, somewhat different, depositional models are briefly presented. Both correspond to an ice front bounded by water, but differ in the relationship of ice to basement topography. The first model is derived from Boulton and Deynoux (1981), who refer to it as the glaciolacustrine valley sediment association, and it is shown in Figure 3. In this association, upward coarsening sequences would correspond to lateral ice-contact terraces and deltas (K and D in the figure), fining upward sequences would represent sub-aquatic fans (AF), and laminated siltstones would be (fjord) bottom muds (M). Slumps (S) may be responsible for blunt nosed conglomerate bodies with vertical contacts, as in the Silverfields paleovalley.

This model is less satisfactory for the following reasons:

MODEL 1: GLACIOLACUSTRINE VALLEY OR PROXIMAL MARINE FJORD



FL fluvioglacial surface
K kame terrace
D delta
AF sub-aquatic fan
M bottom muds
S slump
IG iceberg grooves

Figure 3. A model of sedimentation equally appropriate to the glaciolacustrine valley sediment association, or the proximal glaciomarine environment in a fjord. Key (G) glacier; (C) crevasses; (L) lateral ice cored moraine (largely made up of supra-till); (FL) fluvioglacial surface; (LT) lateral ice-contact terrace (kame terrace); (E) esker; (K) kame; (F) alluvial fan; (FD) fan delta; (D) delta; (AF) sub-aquatic fan; (I) iceberg; (IG) iceberg grooves; (M) lake (fjord) bottom muds; (S) slump; (T) turbidity flow. This is Model 1, a glaciolacustrine valley or proximal marine fjord. Modified after Boulton and Deynoux (1981).

Pebbly wackes that are in sharp contact with laminated siltstones (Photo 9) may represent deposits of grounded ice or of debris flows.

1. Deltas are not composed of locally eroded basement material and are not overlain by fluvial conglomerates.

Model 2: Grounding of an Ice Shelf

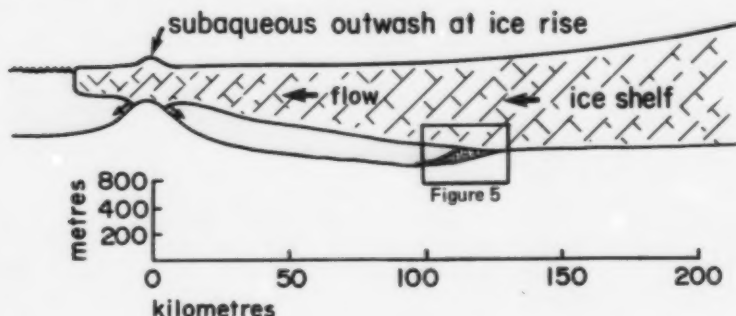


Figure 4. Section of an ice shelf (modified after Orheim and Elverhoi (1981).

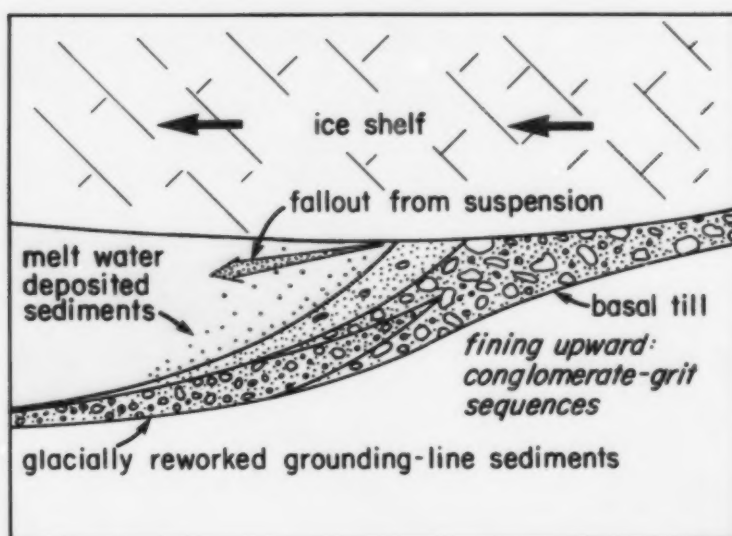


Figure 5. A concept of the sediment distribution at the grounding line with outflowing meltwater (modified after Orheim and Elverhoi (1981).

2. Clast source direction is not related to the trend of the paleovalley.

The second model is taken from recent studies of sedimentation below the ice shelf and outlet glaciers of the Antarctic ice cap (Sugden and Clapperton (1981); Drewry and Cooper (1981); Orheim and Elverhoi (1981); Kurtz and Anderson (1979)). It is characterized by the following features (see Figures 4 and 5):

1. flotation of the ice shelf, ice streams, and outlet glaciers
2. bulk debris release at the grounding line of either shelf or glacier

3. ice rises over projections in basement topography
4. a dominant lithology of laminated deposits and massive aqueous till
5. spatial variations in the proportion of local and exotic clasts where ice grounding on basement highs occurs
6. extensive ice rafted debris.

This model is more compatible with present field observations and the basement topography map. As ice was partly floating, the basement topography did not undergo carving nor were basement rocks striated or fluted. The transport of exotic clasts (from the

east?) was not controlled by the submerged northeast - southwest basement valleys. Basement highs such as the Lorrain granite became ice rises and a source of clasts that were spread over a wide area to the west. Subaqueous outwash bordered these highs and the highs may have been bevelled somewhat under the ice.

Reservations about the model include the following observations:

1. The presence of varves (couplet bedding) in Coleman Member laminated siltstones suggests freshwater rather than marine conditions.
2. The facies variations of Coleman Member sediments are more localised than one would expect on an Antarctic type continental shelf.
3. The scale of the Antarctic ice shelf, 150 km wide according to Figure 4 may be inappropriate.

The model predicts two provinces of sedimentation based on the location of the grounding line, the position in the environment where the ice mass becomes floating. Kurtz and Anderson (1979) stated:

"Landward of the grounding line, sediments closely resembling terrestrial tills are deposited by subglacial processes. These grade seaward into pebbly muds deposited from floating ice and reworked by bottom currents".

Farther seaward, laminated beds should increase with more gradational contacts and decreasing proportion of clasts. The sediments of the Coleman Member in Henwood Township (Thomson 1968) may reflect such seaward deposition beyond the limit of the grounding line.

Other factors that need to be considered in glacial depositional models include the following:

1. Glaciation and deglaciation result in dramatic changes in water level as well as subsidence and rebound of the crust. These certainly affect sedimentation patterns and positions of grounding lines.
2. Even though ice was probably responsible for transport of exotic clasts, other processes may have been responsible for redeposition of glacial material into various deep basins of the Cobalt Embayment. The presence of ice does not exclude other processes of sedimentation from operating.
3. The presence of basement-derived clasts in Coleman Member sediments does not necessarily demonstrate that basement rocks were subaerially exposed to mechanical weathering. Erosion could take place by freeze-thaw action under glacial ice. With melting of that ice, basement would be drowned without exposure to air.

Economic Geology and Mineral Exploration

INTRODUCTION

The map area encompasses the core of the Cobalt mining area that has been extensively explored for Ag-Co veins. Diamond drilling over the years has been extensive. The exploration targets are very small, veins only a few cm thick. In the past, the tendency was to remove only the immediate wallrock to veins, while at present, wallrock that may contain a few ounce Ag per ton is removed as well as vein material.

Recent mineral exploration activity is fully recorded by Owsicki (1981). It includes diamond-drill programs by Silverside Resources Incorporated and Teledyne (Canada) Limited, on properties in the vicinity of the Mackenzie Fault at the Buckle-Lorrain Township boundary which is outside the map area. On the northwestern side of Cross Lake, Silver Century Limited undertook an extensive diamond-drill program from the underground workings of the King Edward Mine. Teck Corporation extended a crosscut on the 5th level of the Silverfields Mine into Cons Summit Mines Limited ground as part of a joint venture. At the Coniagis Mine (Agnico-Eagle Mines Limited), slope walls were blasted and lower grade wall rock ore was recovered in an open pit operation.

The ore minerals at Cobalt are found in carbonate veins and consist mainly of native Ag and complex arsenides, antimonides, and sulphides. The main elements extracted in order of production are Ag, As, Co, Cu, Ni, Pb, and Bi. According to Halls and Stumpf (1970), the Ag can contain appreciable Hg (up to 8%) and Sb (up to 13%) in solid solution. The deposits consist of mineralized veins and to a small extent of mineralized wall rock.

ORIENTATION AND LOCATION OF MINERALIZED VEINS

The veins occur both separately and in networks. They usually correspond to discrete and narrow fissure fillings; more rarely a wider vein zone corresponding to a closely spaced fracture system is apparent. Ore has also been described within crackle breccias, particularly where veins enter basement. Most veins are subvertical. In Coleman Member sediments, a few veins are subhorizontal and occur along bedding planes. The fracture system hosting the veins has been related to jointing, faulting, and a penetrative "jostling" of the rocks.

The ore veins occur in a variety of rock types, principally:

1. Coleman Member sediments
2. Nipissing Diabase
3. Archean volcanic rocks and interflow sediments

The ore veins have also been found in lamprophyre and granite (very minor amount). Regardless of rock type, a spatial relationship with Nipissing Diabase is evident.

Lithological contacts and rock competence, reaction to stress, clearly affect the geometry of the veins. According to Thomson (1967, p.139) contacts that have been important for ore localization in the camp include:

1. the top contact of the Nipissing diabase Sill against Archean rocks
2. the bottom sill contact against Archean rocks
3. the contact of Cobalt Group sediments over Archean below the sill.

Where the Coleman Member is present, ore occurs largely in the sediment, and where the Coleman Member is absent, the orebodies are in Archean rocks and the diabase.

Various factors have been related to the location of ore veins, these include:

1. erosion valleys in the basement
2. volcanic interflow bands below the veins
3. particular elevation intervals below diabase
4. impermeable barriers (dikes, and so on)
5. base-metal sulphides in the basement
6. structural intersections.

GUIDELINES FOR EXPLORATION

It is apparent that the veins occur in sets regardless of their particular association. Therefore, a typical exploration method has been to simply extend old workings and to drill radial patterns from the end of their extensions.

A careful re-evaluation of the Cobalt area should be made based on examination of the Basement Contour Map, the known distribution of Ag-Co veins, and the elevation of the bottom contact of the Nipissing diabase (see Thomson 1961, Maps P.96a, and P.97a).

Areas of contour extrapolation are not necessarily underlain by Coleman Member sediments, the sediment-basement contact having been crosscut by Nipissing Diabase so that diabase rests directly on volcanic basement. If the trend of the bottom surface of the Nipissing Diabase is known, the extrapolated contours may reveal lenses of Coleman Member sediments sandwiched between the diabase above and the volcanic basement below.

Extensions of known basement depressions should be re-evaluated these include:

1. the Silverfields paleovalley northwest connection to the Cart Lake trough; southwards a possible alignment with a series of depressions underlying the southwestern side of Giroux Lake (see basement contour map)
2. the extension of the valley of the Cyril Lake Fault and its possible alignment with the depressions mentioned above
3. The extension of the Valley Fault structure

Little drilling appears to have been done in the area underlying Contact Bay on Giroux Lake and the peninsula of Diabase Point. This area is in line with the above structural trends. Parts of this area, (northeastern corner of Contact Bay?, may have appreciable thickness of sediment below the diabase).

Source, Timing, and Processes of Ag-Co Mineralization

In spite of a great deal of geochemical analyses and other work encompassing an entire volume of the *Canadian Mineralogist* (Volume 2, Part 1, 1971), the source timing, and processes of Ag-Co vein mineralization remain unresolved.

Possible sources of the Ag include:

1. Archean volcanics and interflow sediments
2. Coleman Member sediments
3. Nipissing Diabase

ARCHEAN ROCKS AS SOURCE

Many of the mineralized veins occur on the upward projection of Archean interflow sediments. Some interflow sediments underlie basement depressions suggesting preferential erosion of these rocks. Basement depressions have also been related to faults (see basement contour map). The sediments contain pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena. Layered sulphides are present in tuffs. According to Petruk and staff (1971a, p.196), the mineralogy is typical of base-metal stratiform deposits. Boyle and Dass (1976, p.414) noted that the rocks which are the richest in elements associated with the Ag veins, are the Archean interflow sediments. These sediments also contained anomalous amounts of Hg not present in other potential source rocks. Patterson (1979, p.228) noted an almost invariable association of Archean base-metal mineralization with Ag-Co vein deposits.

Jambor (1971, p.406) however, pointed out the following:

1. The ore minerals of veins in Coleman Member sediments contain Co, Ni, Ag, and Fe in marked contrast to the base-metal occurrences in the Archean basement.
2. Many veins are not situated above any known interflow sediment.
3. The volume of interflow sediments is too small to be considered a source for all the Ag; unless distillation from considerable depth occurred, a theory forwarded by Halls and Stumpfl (1970).
4. It is unlikely that Ag in veins occurring above a diabase sill is a distillation product of Archean volcanic rocks, which underlie a combined thickness of sill and Coleman Member sediments.

COLEMAN MEMBER SEDIMENTS AS SOURCE

Coleman Member sediments have been proposed as a source of Ag based on analogies with the widespread distribution of base-metal sulphides within these sediments.

Base-mineralization occurs in Archean basement, basement driven breccias, as disseminations within Coleman sediments, and in the wall rock adjacent to Ag-Co veins. It is generally agreed that some remobilization of the sulphides in basement and sediments has occurred. In the case of the latter, sulphides are found as layers within basal Coleman Member laminated siltstones, as impregnations in granitic clasts of exotic origin, and as replacements of pebbles (Petruk 1969, p.523). If Archean base-metal sulphides were recycled into the sediments as

detrital grains and then remobilized, perhaps the silver mineralization originated in a similar manner. Thus, Innes and Colvine (1979) suggested that Ag may have been in the sediments originally, derived from an unexposed silver rich basement terrain to the northeast, or from local source rocks. During diabase intrusion, the Ag was remobilized and concentrated.

Appleyard (1980) has also recently argued for a source of Ag in the sediments. With respect to the Silverfields Mine, Appleyard concluded that elements such as Ca, K, As, Ag, and Sb had been leached from chlorite-spotted siltstones and deposited in other chlorite-spotted rocks as well as the ore veins.

In contrast to the above, several lines of reasoning suggest that Coleman Member sediments are not the source of Ag:

1. The sediments consist largely of unsorted clastic material derived from numerous sources. Ore minerals of any one source (for example interflow sediments) would be dispersed rather than concentrated in Coleman Member sediments.
2. Ore veins are found where no sediments are present, that is in Archean volcanic rocks below diabase.
3. There is no published occurrence of Ag-bearing detrital clasts, or Ag-bearing placers within the Cobalt area.

DIABASE AS SOURCE

The principal argument for diabase to be the source of Ag is based on the fact that (Jambor 1971, p.410) "where there was no diabase, nickel-cobalt arsenide-native silver veins have not been found; where there was diabase, these veins may occur regardless of the type or age of host rock intruded by the diabase". Petruk (1971, p.396) concluded that zoning of major veins is related to the positions of veins with respect to the diabase. Ni-Co arsenides are found close to the diabase, in veins above or below the diabase, while iron arsenides are found farther away. This conclusion is disputed by Halls and Stumpfl (1970, p.281). Jambor (1971) considered many of the vein-filled fracture systems as originating in the contraction of Nipissing Diabase during cooling. However, Halls and Stumpfl (1970) believed the fractures, at least those in the Kerr Lake arch area, developed or were reactivated as a result of the post-diabase Penokean and Grenville Orogenies. Regionally, the ore deposits at Cobalt are part of a Cobalt-Sudbury metal zonation related to Nipissing Diabase intrusion and centred about dike-like bodies at Sudbury which contain metal sulphides of magmatic origin (Card and Pattison 1973).

Proponents of diabase as a source of Ag must reconcile the following:

1. The ore veins cross-cut the diabase and its thermal aureole.
2. Ore is found in the Cobalt Lake Fault. This fault clearly displaces diabase. Also, an ore vein crosses the Valley Fault, which probably is a branch of the Cobalt Lake Fault.

In the first point, the proponents note that aplitic differentiates of the diabase cross-cut the diabase.

In the second point, the proponents note that the Cobalt Lake Fault is relatively barren of ore and post-ore movement is evidenced by some slickensided and brecciated ore.

The ore zones on either side of the Cobalt Lake Fault are apparently displaced (Thomson 1967, Figure 1). Thomson stated that this is not a consequence of faulting, but does not explain his reasoning. Some ore associated with smaller faults is clearly post faulting, for example, an ore vein occurs along fault 64, and ore is found in the brecciated wall rock adjacent to the Le Heup Fault, but the age of these faults relative to Nipissing Diabase is not known.

Halls and Stumpf (1970) stated that the widespread occurrence of wallrock fragments embedded in carbonate gangue suggests overlap of tectonic phases and mineral deposition. They concluded the mineralization to be "polyphase and polyascendent". If more than one period of mineralization was active, the latest period of mineralization may be recognized by these crosscutting relationships, that is, the vein crossing Valley Fault. The earliest (unrecognized) period may be the primary period of mineralization.

DIABASE AS HEAT SOURCE

The origin of the Ag-Co veins may be considered from the viewpoint of processes responsible for concentrating the ore minerals rather than the viewpoint of determining a single source for the Ag. In this regard, A. Andrews (geologist, Mineral Deposits Section, Ontario Geological Survey, personal communication, 1981) stressed that the mineralogy of the diabase and its narrow contact aureole indicate that it was "dry" during intrusion, and was not a source of hydrothermal solutions. Any such hydrothermal solutions resulting from differentiation and separation of an aqueous phase should be found above the diabase and not below. In a study, A. Andrews (geologist, Mineral Deposits Section, Ontario Geological Survey, personal communication, 1981) has developed a model based on thermal convection of fluids in the sediments. The diabase acted as a heat source resulting in long term convection and leaching of available sources of Ag, in Coleman Member sediments, volcanic interflow bands, and so on. Such convection was enhanced where sediments were trapped in a valley "pocket" beneath the diabase or in other structural traps governed by the arch or basin geometry of the sill. Convection also continued when the outside of the sill was cool and the inside hot; this resulted in fracturing and some vein deposition in the sill itself. In fact, hydrothermal solutions derived from such fluids could result in autometamorphism of the sill itself.

The author believes that convection would occur as a result of heating the connate water-bearing sediments from below, but not from above. Heating from above as at the Silverfields Mine, where dia-

base overlies sediments, would result in thermal stratification.

However, Andrews considered that thermal expansion and density decrease due to rapid heating would drive the fluid down, away from the overlying impervious diabase. The diabase, therefore, would act as a hydraulic heat pump to drive fluids through any available fractures. If the rocks were initially saturated with fluid, this would result in mass convective motion.

Chlorite spotting suggests two principal phases of hydrothermal activity. The first phase may correspond to intrusion of Nipissing Diabase and the thermal release of fluids into surrounding rocks including the structurally weak and relatively permeable volcanic interflow bands. Connate fluids could be released and squeezed out as a consequence of differential compaction of Coleman Member sediments against rigid basement during intrusion.

The second phase of hydrothermal alteration and chlorite spotting perhaps occurred with cooling and contraction of the diabase (not necessarily uniform) and migration of the currently ore-bearing fluids towards the diabase, resulting in vein filling of abundant fractures in various host rocks. According to Andrews, if a convective fluid flow system was established, the fluid would gradually encroach on the diabase as it cooled from the outside in.

Several objections exist, however, in considering the diabase as a heat source acting on fluids within the sediments:

1. Arsenide deposition begins at temperatures slightly below 600°C, according to Petruk (1971). The country rock was relatively cold. How did the diabase maintain such high temperatures in the fluids when it itself was already undergoing cooling and fracturing? Andrews, however, considered that most of the mineralization occurred at comparatively low temperatures (<300°C).
2. How were some elements such as Ag, Co, present in trace amounts in host rocks, leached and concentrated to a great extent in the fluids, while considerably more abundant elements such as Cu, Pb and Zn, in volcanic interflow rocks, were not?

CONCLUSIONS

The richness of the Ag-Co veins relative to wallrock and potential source rocks indicates a long term and particularly effective process of concentrating the elements that constitute ore minerals. A possible process involves diabase as a heat source acting on fluids within the host rocks. This leaves unexplained how Ag and Co were concentrated to a great extent while more abundant Cu, Pb, and Zn were not. The author therefore believes the ore forming elements came from the same reservoir as the Nipissing Diabase. This is in keeping with a regional metal zonation related to Nipissing Diabase intrusions (Card and Pattison 1973).

Appendix I

DELINEATION OF THE FIRSTBROOK MEMBER OVER 89 TOWNSHIPS IN THE COBALT EMBAYMENT by David S. Thompson

The Gowganda Formation is stratigraphically the lowest of a group of formations, which together comprise the Cobalt Group, a group of flat lying, relatively unfolded sediments, which in the townships surrounding Cobalt, Ontario, overlie folded basement Archean rocks with profound unconformity.

Robert Thomson (1957) considered the Gowganda Formation to be divisible into two formations, as opposed to Members: the Firstbrook and the Coleman. Thomson followed the criteria that a formation should generally possess recognizable contacts traceable in the field, a considerable thickness, and a sufficiently large areal extent to show on geological maps.

In the townships immediately surrounding Cobalt, The two-fold divisions of the Gowganda Formation appear to meet these criteria. The Coleman Member is distinguished by its conglomeratic nature, consisting mostly of pebbly wackes. Within the Member a considerable variation both laterally and vertically in bedding and the proportion, size, angularity, and shape of clasts is found.

Overlying the Coleman Member with a sharp lithologic contact, in the Cobalt area, is the Firstbrook Member, consisting principally of well laminated and massive mudstone. Ranging in size from 0.1 to 5 mm, the laminae commonly alternate in colour forming couplets of red and grey-green.

Thomson (1957) felt that the Firstbrook was readily identifiable as a formation in areas as far away from Cobalt as Solace Lake in Selkirk Township. Thomson (unpublished manuscript) further believed that the "upper thin bedded greywackes of the Gowganda Formation" which Roscoe (1969, p.12) observed extending southwest of Cobalt to Wanapitei Lake, were in fact part of the Firstbrook "Formation". Others, however, working in this southwestern location have disagreed (Meyn 1972).

John Wood of the Ontario Geological Survey observed that the Gowganda Formation was in fact divisible into two distinct lithologic units near the Town of Cobalt, but also noted that farther afield, in areas north and west of Lake Wanapitei (District of Sudbury), such a "simple two fold division was not apparent" (Wood 1979).

The definite, probable and possible extent of Firstbrook Member rocks over 89 townships around Cobalt, Ontario, is shown on Chart A, back pocket. In nearly every case, an effort was made to consult at

least two maps per township to determine the most accurate description of the rock types present.

Regions of outcrop identified on a map as part of the Firstbrook Member, were classified as "definite Firstbrook". In other areas, a set of criteria had to be used to identify the formation. Criteria for identification include 1) the presence of laminae or well developed bedding, 2) the absence of clasts, 3) a geographic location more or less contiguous with areas identified as "definite Firstbrook", 4) an apparent stratigraphic position between the Lorrain Formation and Coleman Member type, 5) a lithology of argillites, siltstones, and non-pebbly wackes, 6) the presence of a reddish colour. Areas of outcrop meeting most or all of these criteria were identified as "probable Firstbrook". Those areas whose description and stratigraphic position were ambiguous were termed "possible Firstbrook" (see Chart A, back pocket).

In general, geologists have observed that the contact of Firstbrook-type rocks with underlying basal conglomerates is sharp, while the contact with overlying Lorrain arenites is more gradational.

The principal area of exposed Firstbrook is found in townships roughly lying west of the Cross Lake Fault, north of Lake Temagami, east of Lady Evelyn Lake, and south of Henwood Township. If the areas underneath nearby outcrops of Lorrain Formation and Nipissing Diabase are considered, the area of Firstbrook rocks approaches an extent of 2500 km².

Areas of Firstbrook extend outward from this principal area. One extension is westwards to Nicol Township, while another in the south extends in a parallel manner to Urwin Township. A third reaches southward from northern South Lorrain Township to Ridell Township. The probable areal extent of the Firstbrook "Formation" is another 2500 km² in addition to the 2500 km² inferred above.

Considerable thicknesses of such Firstbrook rocks have been encountered in diamond-drill holes in scattered locations over the map area. The Eplet diamond-drill hole in Henwood Township for instance, intersected 600 m of Firstbrook rock, and more than 40 km to the southwest, drilling intersected 250 m of non-pebbly greywacke adjoining the Lorrain Formation in Selkirk Township. (Thomson, unpublished manuscript).

The areal extent, thickness, and lithologic distinction of the areas delineated here as probable and definite Firstbrook type rocks support Thomson's contention that this "Member" merits "Formation" status. This compilation and subsequent conclusions, however, need to be "ground truthed" by a general field reconnaissance of delineated areas.

Appendix II

BASEMENT CONTOUR MAP — NOTES ON CONTOURING

The basement contour map represents the contoured surface of the Archean volcanic basement beneath its sedimentary cover of Huronian, Coleman Member of the Gowganda Formation, sedimentary rocks. The topography is discontinuous across the plane of the Cobalt Lake Fault, which is a major fault. Therefore, the areas on either side of the fault were contoured separately. Each area itself contains minor faults that affect the pattern of the contour lines. Contour lines lying within 25 feet of each other as projected on the horizontal plane are skipped on the plot. Since the contour interval is 25 feet, this indicates a basement slope greater than 45°. Such steep slopes may indicate the position of basement faults. Positions of known faults are noted on Chart A, back pocket.

A general purpose contouring program (GPCP II, Calcomp Limited) was used to contour irregularly-spaced control point values. Computer input data included a data deck, JCL (job control language) cards, parameter, and sequence cards. Output data consisted of a printout and plot tape. The program calculates values for a rectangular array or grid of data points. These regularly spaced data point values are then contoured. Several trial plots are necessary to adjust variables. These variables (with respect to any given data (control) point) include:

1. the number of neighbourhood points used for grid generation and contouring
2. the maximum radius of search for neighbourhood points
3. the grid interval for the rectangular array of data points

The final plot corresponded to the following values for these variables:

1. 11 neighbourhood points
2. 1000 feet radius of search
3. 100 foot grid interval

Increase the number of neighbourhood points within a given radius of search improves the positional accuracy of the contour lines but decreases the area of contouring. A compromise between accuracy and area coverage was necessary. As a result a

few sparse sets of control point data are not contoured.

Without the cooperation of, and information received from, Agnico-Eagle Mines Limited, Canadaka Mines Limited, and Teck Corporation Limited (Silverfields Division), this map would not have been possible; their contributions are gratefully acknowledged.

BASEMENT CONTOUR MAP — SOURCES OF INFORMATION

Data compilation by Andrew Legun 1981, assisted by Bill Arnott.

Data was compiled from geological maps and subsurface mine and drillhole plans. The following sources of information were utilized:

Teck Corporation (Silverfields Division), Cobalt, Ontario.

Canadaka Mines Limited, Cobalt, Ontario

Agnico-Eagle Mines Limited, Cobalt, Ontario

Knight, Cyril W.

Geology of Mine Workings of Cobalt and South Lorrain Silver Areas; Ontario Department of Mines, Annual Report for 1922, Volume 31, Part 2, (Out of print).

Ontario Department of Mines Preliminary Maps:

Maps P.97 and P.97a covering parts of Coleman Township.

Maps P.96 and P.96a covering parts of Coleman and Gilles Limit Townships by Robert Thomson, 1961.

Robert Thomson's maps (P.96, P.96a, P.97, P.97a), modified by a Canadaka Mines Limited drill-plan overprint served as the geographical base for positioning the data points.

Every effort has been made to ensure the accuracy of the geographical position and value (elevation) of the control points. Some discrepancies were apparent for data compiled for the same area from different sources. In these cases, data was selectively accepted or rejected depending on "anomalous" values.

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**MAPS
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